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Beyond the hype of Hyperloop: An analysis of Elon Musk's proposed transit system

By Brian Dodson

August 22, 2013

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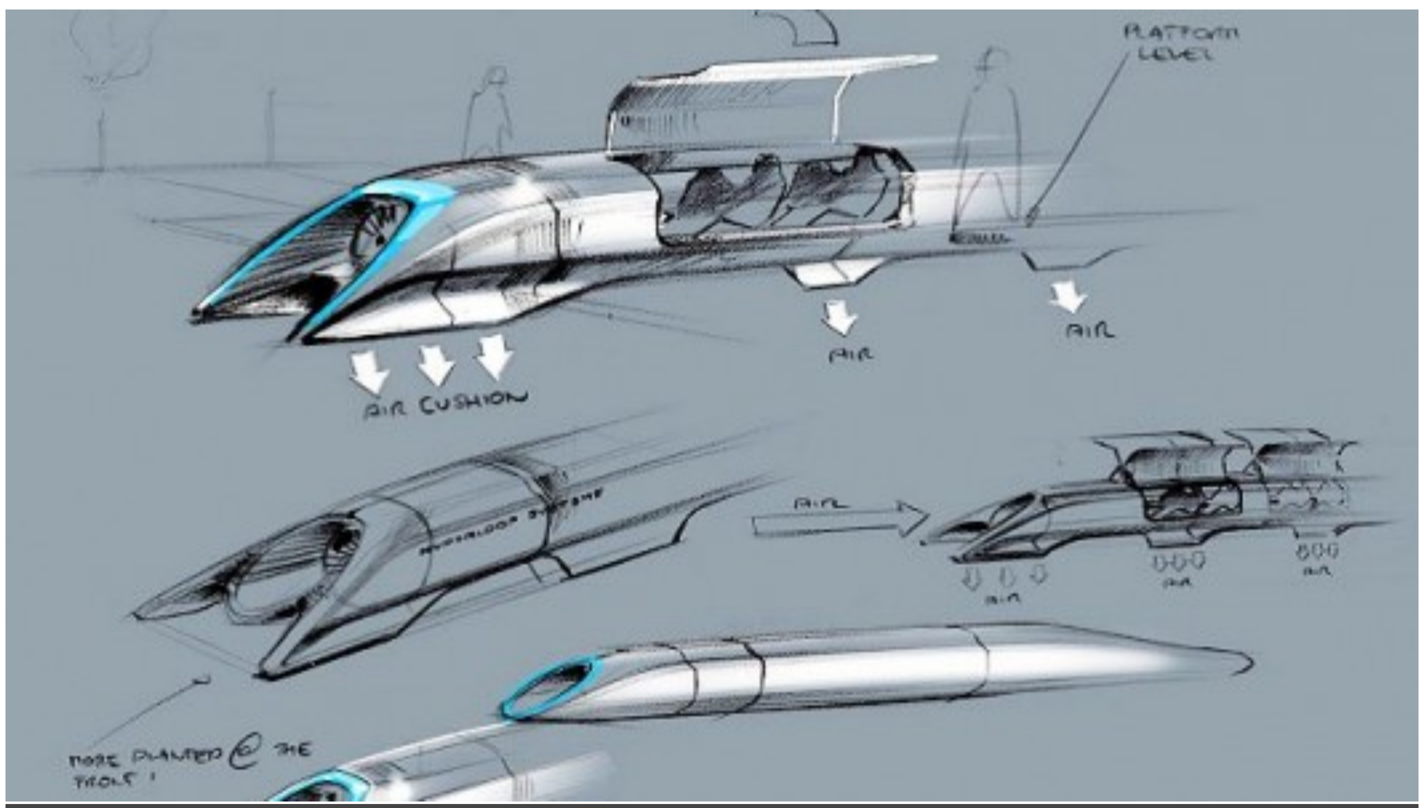

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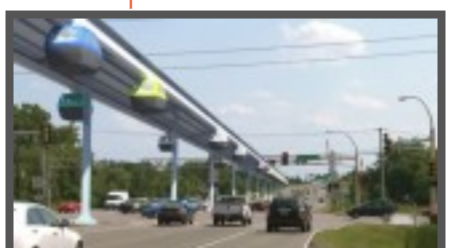
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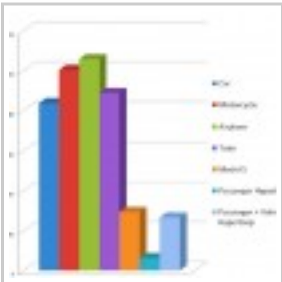
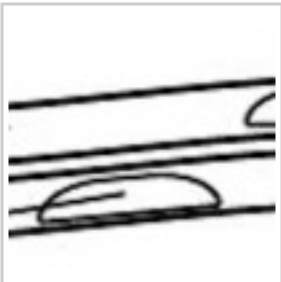
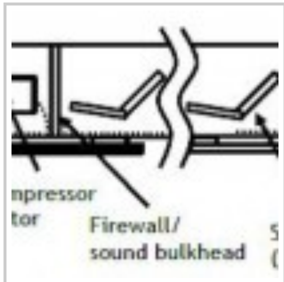
Image Gallery (28 images)

Now that the media kerfuffle surrounding Elon Musk's Hyperloop transit system proposal has settled down to a dull roar, it's a good time to step back and consider in detail some of the real innovations and difficult issues raised through analysis of the 57-page Hyperloop plan.



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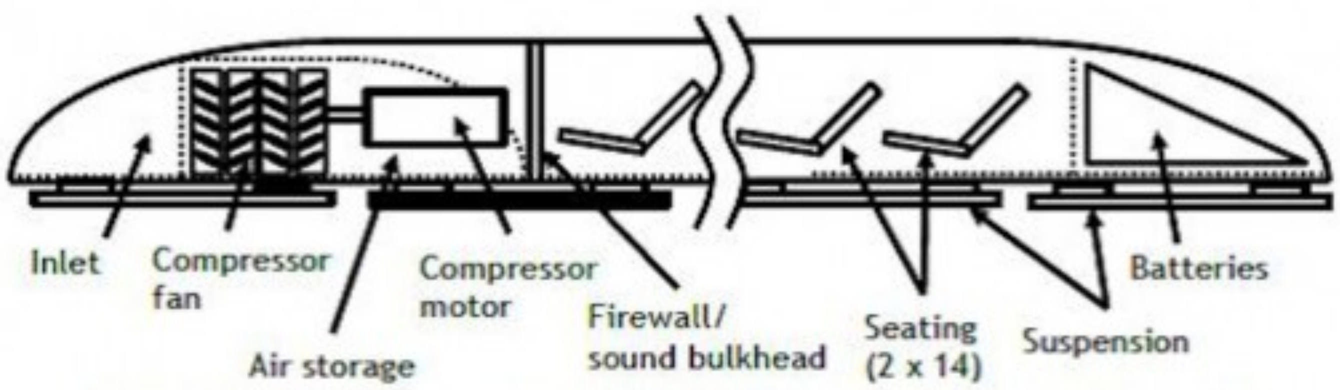
The shortest description of the Hyperloop is Musk's own *bon mot*: "It's a cross between a Concorde, a rail gun, and an air hockey table."

A slightly more complete description of the concept is that of an elevated, reduced-pressure tube that contains pressurized capsules driven within the tube by a number of linear electric motors. These capsules move with very little friction or drag owing to air bearings that ride on the inner surface of the tube, and a combination of active and passive means to reduce the negative effects of choked airflow on the transportation system.



In this article I am only considering the science and engineering aspects of the Hyperloop. While acknowledging that political issues may actually determine its fate, what concerns us here is whether or not it could work.

A Quick Overview

A reaction many people have to the Hyperloop is that there is nothing new here. While it's fair to say that all inventors are standing on the shoulders of giants to a certain degree, there are in fact very real innovations in Musk's proposal.

The Hyperloop has essentially no relationship with the old pneumatic tube transports beyond a certain similarity of appearance. There is, however, quite a bit of overlap with earlier proposals for reduced pressure or vacuum-tube transports. In particular, the early theoretical and experimental work of Robert Goddard, the inventor of the liquid fuel rocket, appears to have the greatest overlap with the Hyperloop.

Goddard's notes about reduced pressure transports sat in storage for over 30 years, only surfacing after his death in 1945. In US patent 2,511,979, he describes nearly every major feature of the Hyperloop save for the use of linear electric motors for propulsion (he preferred using reaction motors for propulsion), and using special apparatus to minimize the detrimental effects of choked airflow around the capsules. Goddard also described the use of

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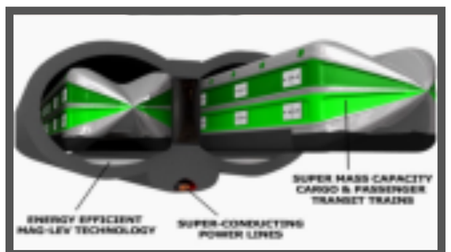
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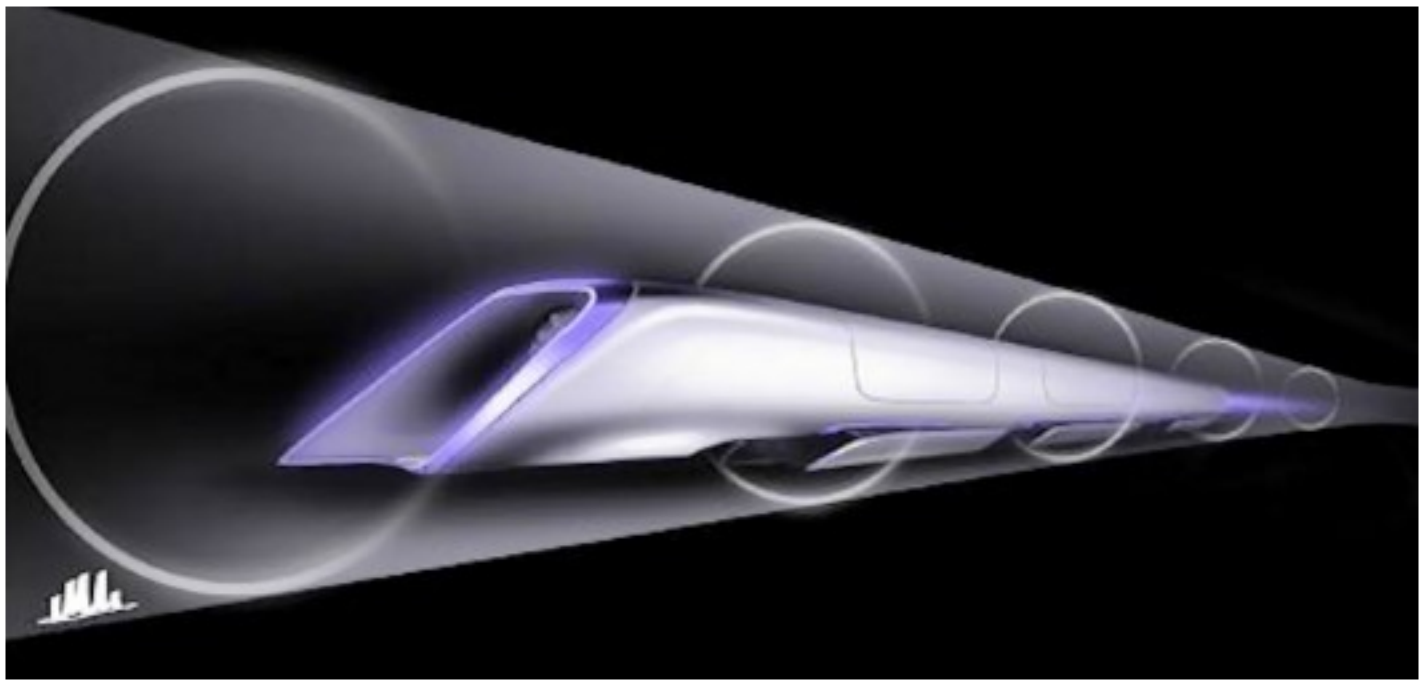
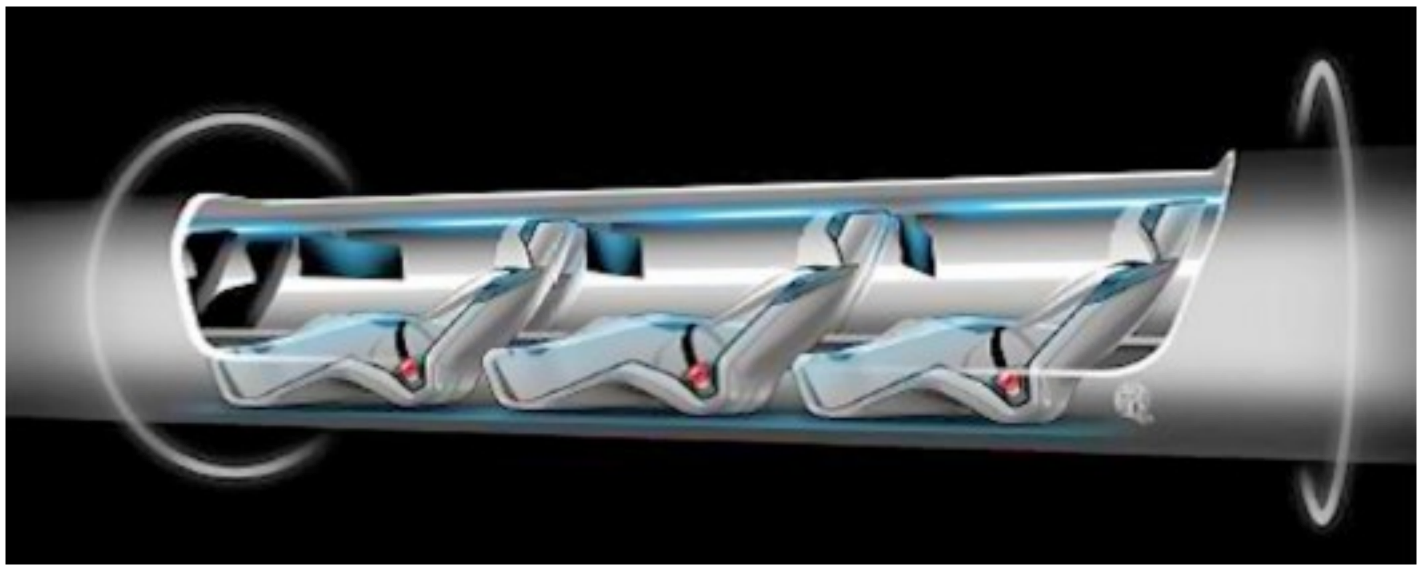
air bearings, but of a very different sort than proposed for the Hyperloop. Many others, of course, *have* suggested the use of linear electric motors.

To sum up, it would appear that the main innovations in the Hyperloop proposal are the type of air bearings used to reduce friction forces on the moving capsules, and design elements that avoid the limitations encountered when the airflow around the capsules is choked. Let's take a closer look at these additions.

The Concorde part



The Concorde portion of the Hyperloop is the capsule that rides within the tube. A passenger-only Hyperloop capsule holds 28 passengers in side-by-side pairs. The capsules are 1.35 m (4.4 ft) wide and 1.1 m (3.6 ft) tall.



The riding position is rather like that of an airline seat with the back reclined and feet thrust forward. The amount of seating room will be similar to that of an economy airline seat where everyone has their seatback down.

Oddly, the length of the Hyperloop capsules is not directly addressed in the proposal. However, given the number of passengers, and the statement that the rotor on the capsule is 15 m (49 ft) in length, the total capsule length is probably in the neighborhood of 25-30 m (~80-100 ft) ... which interestingly equates to a scaled-down Concorde fuselage.

The most important innovations appearing in Musk's Hyperloop proposal have to do with reducing the drag and friction associated with a capsule moving through a tube. A long-standing approach to part of this problem is to reduce the pressure of the air in the tube. This reduces simple air drag and enables the capsule to move faster than through a tube at atmospheric pressure.

This isn't enough however. If the capsule fills too much of the cross-section of the tube, the air won't have time to flow around the capsule as it moves. In this condition, called choked flow, some of the air will back up in front of the capsule, and eventually the entire column of air in the Hyperloop tube is being pushed ahead of the capsule. When this happens, the friction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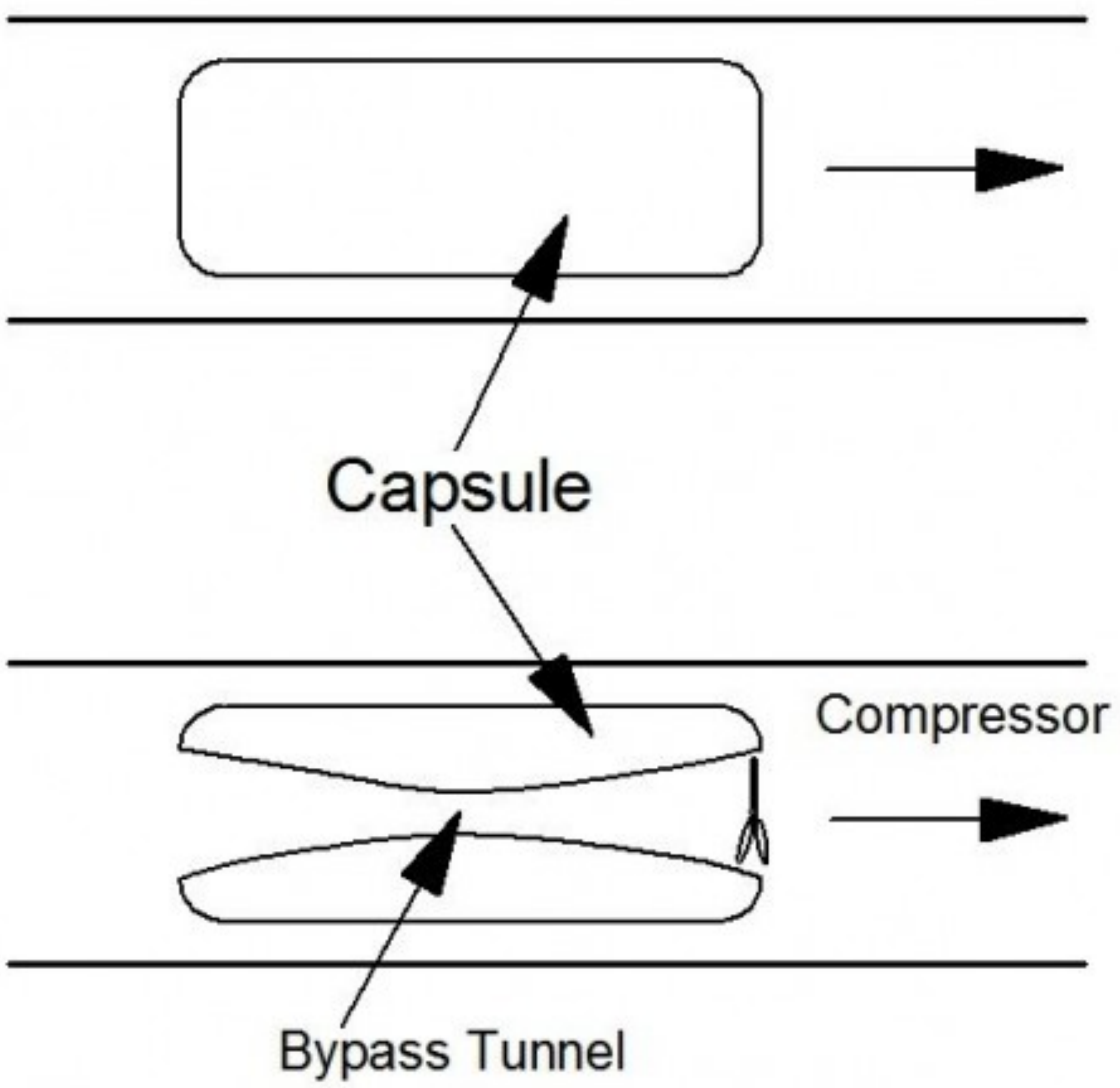
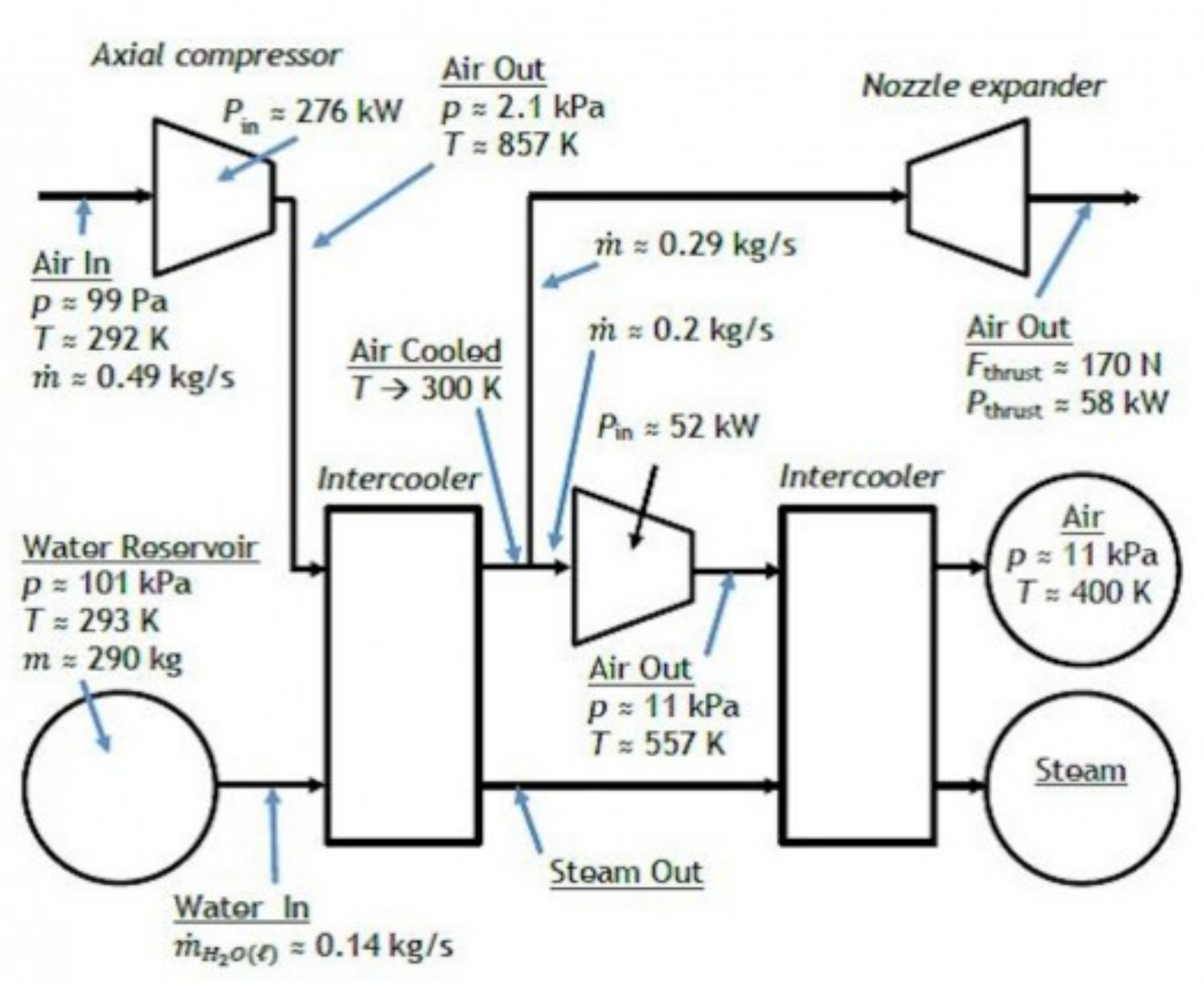
between the air and the tube wall becomes enormous.

Choked flow begins when the pressure ahead of the capsule becomes about twice the pressure following the capsule. Given the Hyperloop dimensions and operating conditions, this starts at speeds around 500 mph (~800 km/h), and is associated with a dramatic increase in air drag.

To avoid being limited to these speeds, Musk's team has introduced a new idea for reducing pressure in the tube. They propose installing an air compressor in the front of the capsule to pump the air which will not flow around the capsule and send it to a bypass nozzle at the rear of the capsule. This reduces the amount of air that must flow around the sides of the capsule, thereby enabling capsule speeds near Mach 1.



In the passenger-only Hyperloop capsule design, an air compressor mounted at the front of the capsule compresses about half a kilogram of air per second to a pressure 20 times larger than the initial pressure, in the process raising the temperature of the gas to about 585°C (1085°F). This will require an air compressor powered by a 325 kW (436 hp) electric motor.



There does appear to be some inconsistency on the use of an air compressor in Musk's proposal. In the text on page 17, it appears to state that a portion of the compressed airflow is split off to be bypassed through the capsule before the remainder is cooled. However, in the drawing on page 18 (shown above), it appears that the bypassed air is split off after the entire output of the compressor is cooled.

It seems clear to me that the preferred situation would be that described in the text, as the cooling requirements of the capsule wind up being 60 percent smaller if the bypass air is not cooled within the capsule, especially as the amount of cooling required has been raised as an issue by some commentators. I will assume this arrangement below, but will also keep an open mind for ideas as to why the cooling of the bypassed air makes sense.

The bypassed air, at a mass flow rate of about 0.3 kg/s, is directed to a nozzle at the rear of the capsule, which also allows the bypassed air to supply additional driving thrust in the neighborhood of 150-200 N (35-45 pounds), or about half the thrust required to maintain a speed of 310 m/s (700 mph).

The remaining 0.2 kg/s of air output from the compressor is cooled to around room temperature mainly by converting water to steam and hot water in an intercooler. Once cooled, the air enters a second compressor, which increases the air pressure to 11 kPa, or about 7 N/square meter (1.6 psi). This doubly-compressed air is sent through a second intercooler that reduces the air temperature to about 125°C (260°F), from which it is directed to supply the air bearings.

The proposal suggests that about 0.14 kg/s of cooling water will be required to supply the intercoolers. This is a typical water flow rate for a racing intercooler mounted between a turbocharger and an engine to cool the air charge, thereby increasing the maximum power of the engine. The intercoolers for the Hyperloop capsules will have somewhat different engineering specifications, but suitable technologies exist in the market. It will only require adapting those technologies to this new operational regime.

For a one-way trip from end to end, about 400 kg (882 lb) of water must be available for cooling. This would fit within a square tank less than 0.75 m (2.5 ft) on a side, easily fitting in the Hyperloop capsule. The tank to contain

the hot water and steam generated would be somewhat larger, but as the required cooling is only enough to convert one-third of the cooling water into steam, this problem may be solved by steam condensation once past the intercoolers. These tanks, along with the batteries powering the capsule systems, are configured as modules to be swapped out at the beginning of each trip through the Hyperloop.

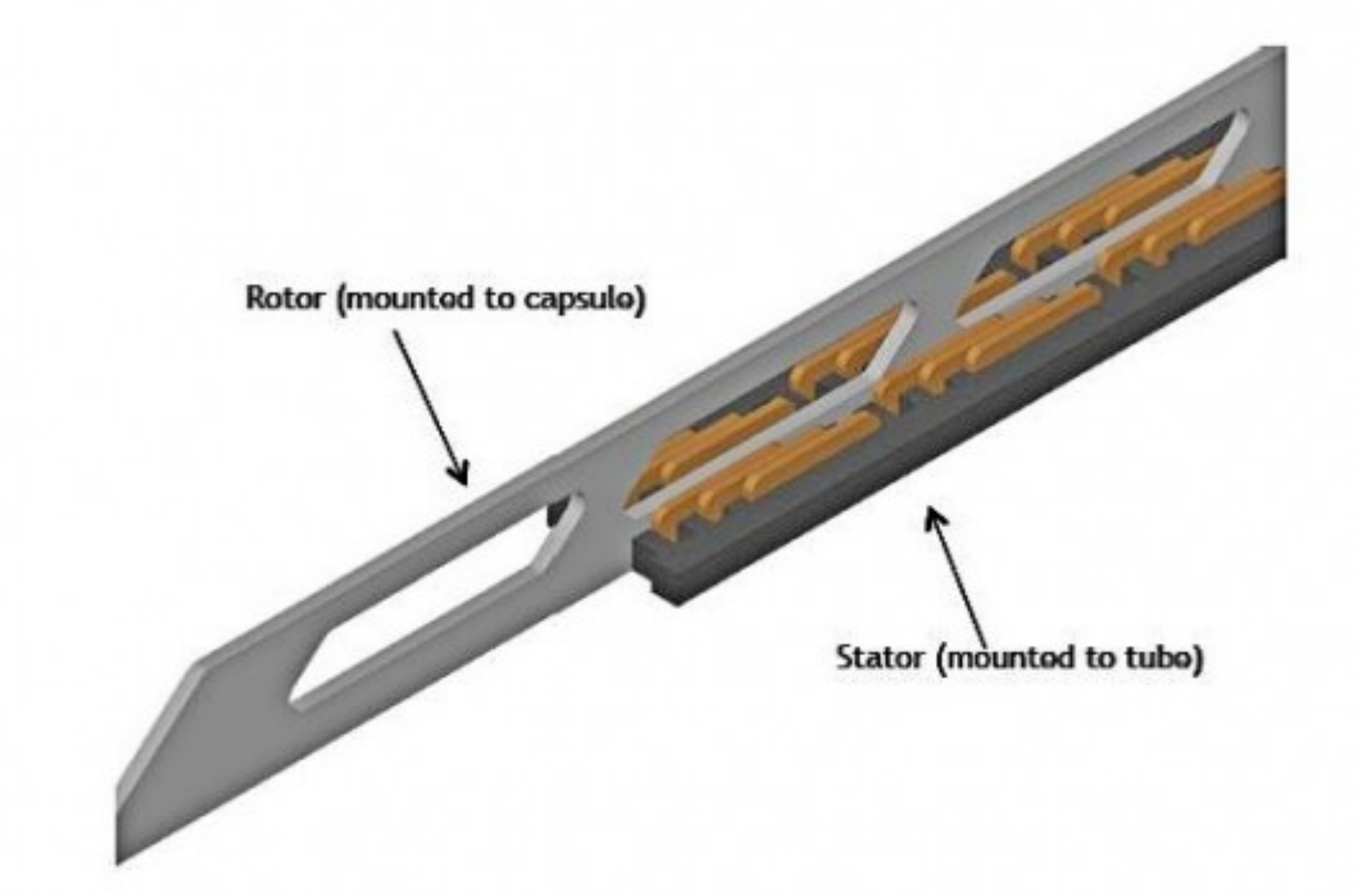
In summary, these innovations reduce the operating pressure of the air inside the tube to about one-thousandth of atmospheric pressure, or about 100 Pa (0.015 psi). This reduces simple air drag to the point that only about 100 kW of motive power is required to overcome the drag at 940 km/h (700 mph). Operating a Hyperloop at reduced pressure is not only possible, but practical. A streamlined design is still required to minimize drag forces though, as the capsule shape diverts the air in the tube to pass around the sides.

The Rail Gun part

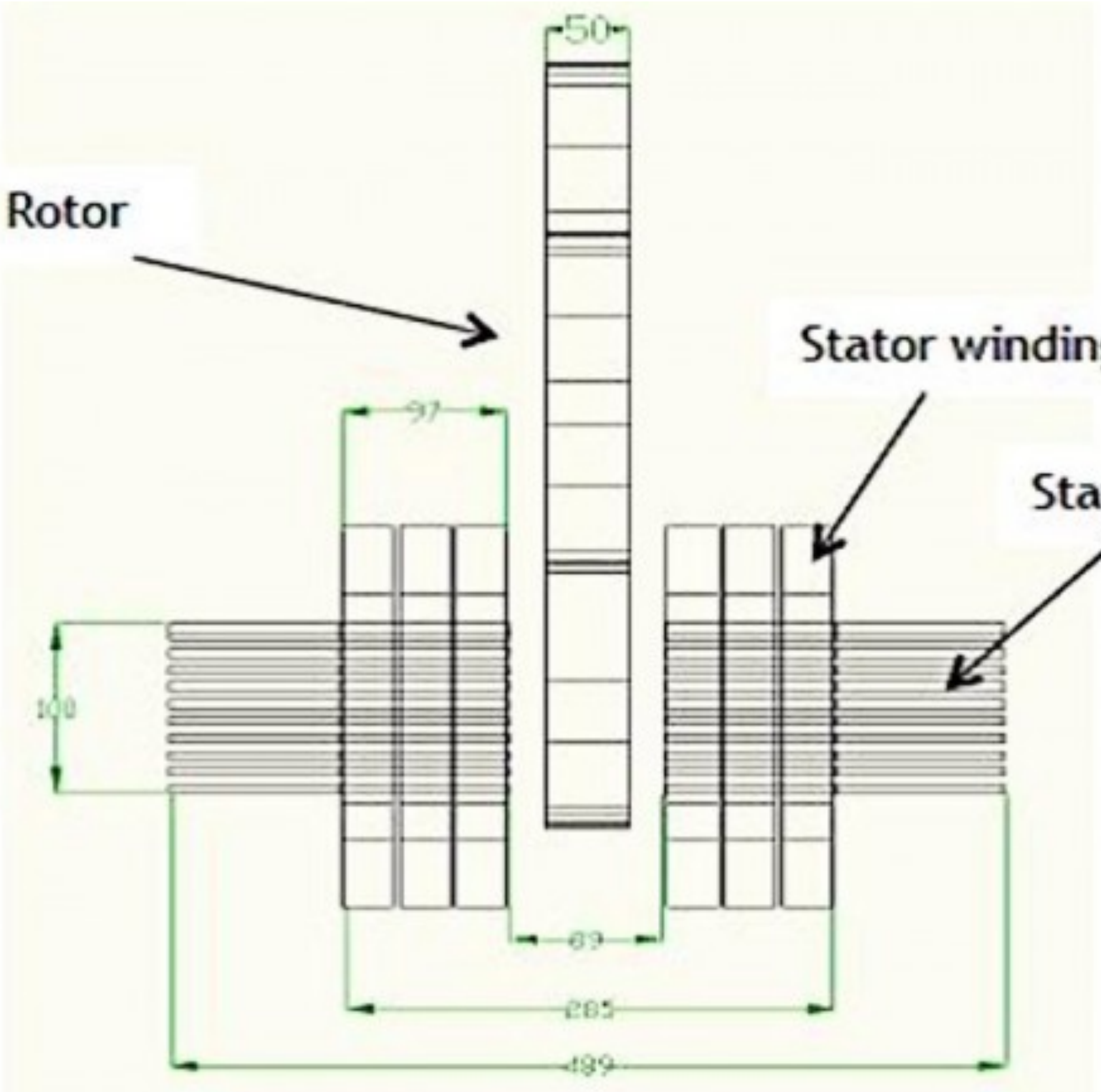
The rail gun aspect of the proposed Hyperloop is the set of linear electric motors that accelerate or decelerate the capsule at the appropriate times. The route chosen for the Hyperloop places capsule restrictions in the various parts of the route. The reason for this is because the lateral acceleration experienced by the passengers would become rather uncomfortable at about 0.5 g, and this lateral acceleration becomes greater at larger speeds and for smaller turn radii.

Musk's team has designed a route that allows three different capsule speeds. Near the ends, the velocity is limited to less than about 300 mph (480 km/h). In hilly regions where the Hyperloop roughly follows Interstate highways, the capsule speed can be increased to 555 mph (890 km/h). Finally, the longest segment follows I-5 up the center of the state requiring only the most gradual of turns, and can allow capsule speeds of 760 mph (1,220 km/h.) Remember that the fastest speeds are only accessible because of the air bypass compressor in each capsule.

The various speed limits require that the Hyperloop operators be able to control the speed of the capsules through a number of accelerations and decelerations. This is the role of the linear induction motors. The hardest job is the acceleration for the I-5 portion of the route, when the speed must be increased from 300 mph to 760 mph at an acceleration of 1 g. This is the accelerator that will be described below, but others would be required in other locations along the route.



The linear induction motors are extremely simple from a mechanical point of view. In the Hyperloop design the only part of the motor on the capsule is the rotor. The rotor is a simple piece of aluminum 15 m (49 ft) in length, 0.45 m (1.5 ft) tall, and 5 cm (2 in) in width. The induced current flows mainly near the rotor surface owing to skin effect, so the interior of the rotor can be hollow to save weight.



The rotor rides between magnetic elements of a stator, which are permanently affixed to the Hyperloop tubes in the locations required, and extend the full length over which acceleration or deceleration is to be carried out. For example, the stator of the motor that accelerates the capsules to 760 mph is a full 2.5 miles in length, and weighs over 3,000 tons (2,722 tonnes), so it is happy to remain stationary. Each linear induction motor can use up to 65 MW during peak operation.

By altering the control and power circuit controls, the linear motors, instead of adding motive power to accelerate the moving capsules, can function in reverse, drawing electrical power from the kinetic energy of a capsule to slow it down. Rather like a regenerative brake on a car, the linear motors store this power for later use. Such regenerative systems can be as much as 85 percent efficient, so that most of the energy required to power a capsule through the Hyperloop can be drawn from power saved from the slowing of the previous capsule's journey.

Musk's proposal also outlines a solar power system to power the Hyperloop. Based on covering the upper surface of the twin Hyperloop tubes with solar cells, this solar array is projected to supply about 57 MW of electrical power on average, while the Hyperloop is expected to consume an average of only about 21 MW. This being solar power, it is clear that power must be shuttled back and forth between the Hyperloop and other utilities, but that is a routine process. In addition, a battery array would be required at each stator station, as the peak powers required locally are several times the average supply. The batteries can also be used in a regenerative braking mode to store the kinetic energy of a capsule. The excess power can be sold to provide around US$25M per year, which will help with Hyperloop operational costs.

Overall, the rail gun part of the Hyperloop is a fairly standard (if gigantic) piece of engineering.

The Air Hockey Table part

The third of Musk's triad is the air bearings upon which the capsules will ride with a minimum of friction. The air bearing best known to many of us is the little puck that slides around on an air hockey table. Pressurized air comes out of a grid of small holes on the hockey table surface, and the puck is lifted by this air. Air bearings provide nearly frictionless motion.

Most modern proposals for vacuum and reduced pressure trains, as well as open high-speed trains, call for suspending the moving vehicle using magnetic levitation. While this is currently the trendy approach, it is actually quite expensive and difficult to control.

By comparison, air bearings have natural stability, low friction, and long lifetime. Air bearings are also a natural fit for the Hyperloop, in which the capsules already contain a compressor system required to reduce air drag at high speeds. Bleeding off some of the compressed air from the bypass system and using it to feed the air bearings seems a natural synergism.

A Hyperloop capsule is supported by a set of 28 air cushion skis, each of which is 4.9 ft (1.5 m) in length, 3 ft (0.9 m) in width, and is curved to match the inner surface of the Hyperloop tubes. The thickness of the air cushion is between 0.5 and 1.5 mm (20 - 50 mils). The total pressurized area available to lift and support the capsule is about 410 sq ft (38 sq m). As an air bearing is rather stiff in reaction to external forces, each of the skis is mounted to the capsule via a second suspension system.

The pressurized area is crosscut with a number of channels that distribute the 11 kPa air from the second intercooler to feed the air cushion at a mass rate of 0.2 kg/s. This doesn't seem like much, but over a 45 minute transit, over 500 kg (1100 lb) of air must be supplied to the air bearings. Carrying air on each capsule flight does not seem a practical procedure, so diverting some of the bypassed air to this purpose allows the bearing system to function effectively.

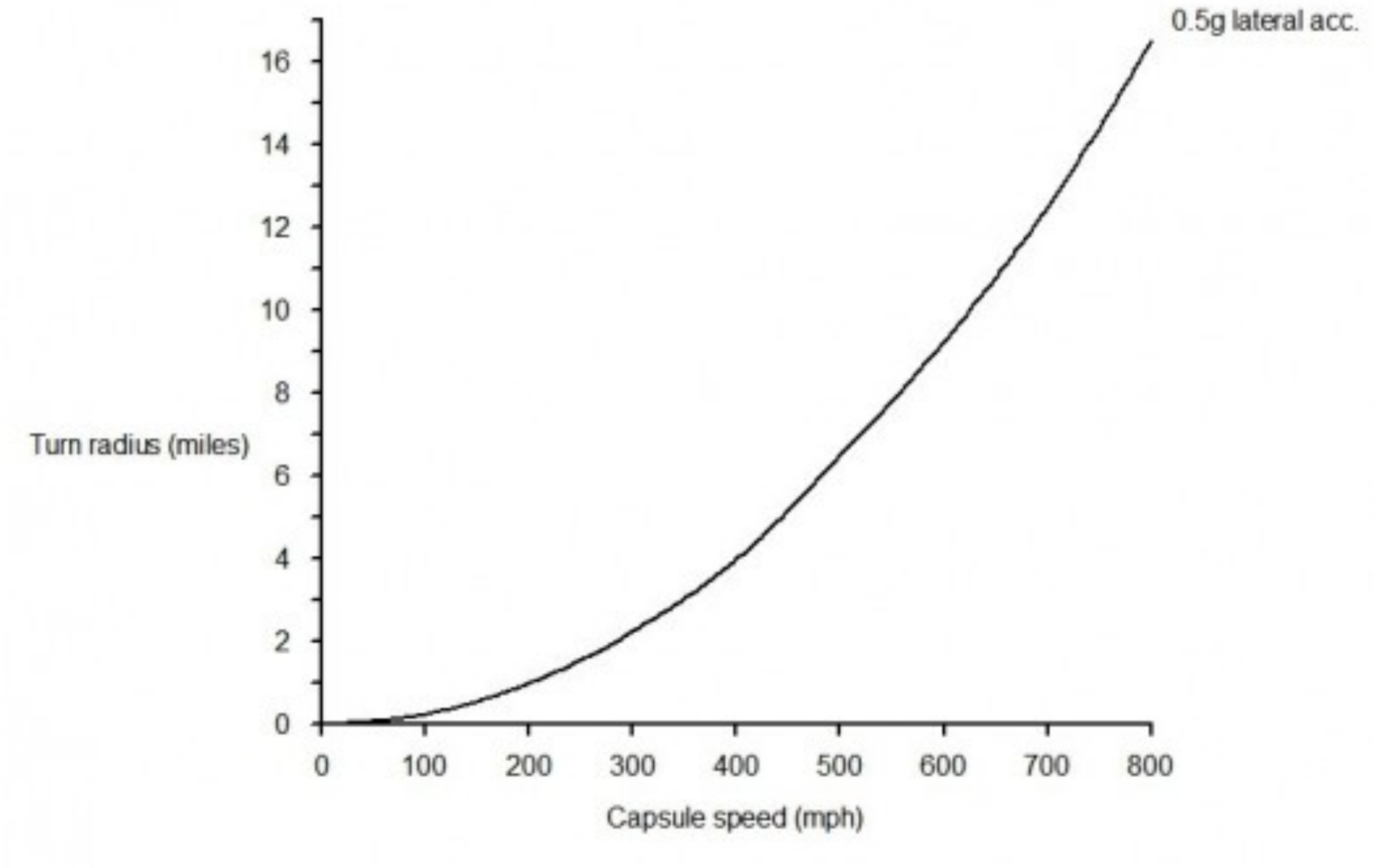
When the capsule is moving rapidly, there is an additional aerodynamic source of air for the air cushions. The front edge of each ski is set higher than the rear by about 1.3 mm. When the capsule is moving rapidly, viscous interactions trap an air cushion in the converging gap between the ski and the tube surface. However, this aerodynamic supply of air is insufficient at any capsule speed for which the Hyperloop is designed – it simply augments the air from the compressor.

The interaction of the air cushion with the tube wall produces a small amount of viscous drag on the capsule. Estimates, however, show that the drag at 760 mph (1220 km/h) is about 31 pounds, or 140 Newtons of force. This is less than half of the total drag estimated at this capsule speed.

Hyperloop Route

The proposed route for the Hyperloop runs from North Valley, CA to the San Francisco end of the Bay Bridge. It ignores the short urban runs, probably because the selection of a route for these runs is mainly a detailed political and economic process.

The route is split into a series of segments. Roughly a particular capsule speed is associated with each of the segments, and that capsule speed is set by the minimum turn radius encountered on that segment.



As discussed, turn radius enters into route selection because strong lateral accelerations (say, above 0.5g) are unpleasant to a passenger. When you follow a curved path, your body wants to travel in a straight line, but it is stuck inside a capsule that is following a curve. This effect, called centripetal acceleration, pushes the passengers sideways. The strength of the effect increases with the square of the velocity and decreases with the turn radius, which results in a simple relationship between turn radius and capsule velocity.

The first segment, stretching from North Valley to Castaic, has a number of sharp turns, limiting the speed to about 300 mph (480 km/h) on that segment. The segment from Castaic to a few miles north of Lebec cuts through some sharp turns along tunnels, and as a result is compatible with capsule speeds of 550 mph (890 km/h).

Form Lebec to the divergence of I-5 and I-580, I-5 is extraordinarily straight, allowing the capsule to travel this segment at 760 mph (1220 km/h). The final segment runs along I-580 with some tunnel bypasses near Dublin. The

speed on this segment starts at 550 mph, and slows to 300 mph as the capsule enters areas with sharper turns.

A property of the Hyperloop that is not obvious at first sight is how few stators are required for operation. If a capsule is given a speed of 760 mph at the start of the I-5 segment, it can coast to the other end (some 230 miles or 335 km distant), and arrive moving at a speed of about 730 mph (1,170 km/h). This is the direct result of the extraordinarily low drag and friction of the proposed Hyperloop. In other words, most of a trip is spent coasting.

Coda

"When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong". Clarke's First Law

I need to echo the common concern that Musk's estimates for the construction costs seem low. For example, the cost of a Hyperloop capsule is projected to be about 1.35 million US dollars. If a comparison is made with light jets having fuselages of similar dimensions to a Hyperloop capsule, it turns out that such jets cost about 10 times Musk's estimated amount. Clearly, a Hyperloop capsule does not have to survive the stress levels that a jet might see, and capsules don't have wings and tail assemblies (not to mention turbofan engines), but still the numbers still seem too low.

More generally, it appears to me that most of the objections presented concerning the Hyperloop are either based on incorrect engineering analysis, or simple prejudice claimed as a truth. There are also a number of pronouncements to which Clarke's First Law would apply.

The real issue is if Musk will take on the project of building a demonstration "Hypoloop." That is the next step, and most of the usual avenues for project development won't swing their doors wide for such a project. Fortunately, Musk is a billionaire, and has friends. We may find out if the proposed Hyperloop is practical sooner than one might expect.

Source: Hyperloop Alpha / Tesla Motors

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About the Author

From an early age Brian wanted to become a scientist. He did, earning a Ph.D. in physics and embarking on an R&D career which has recently broken the 40th anniversary. What he didn't expect was that along the way he would become a patent agent, a rocket scientist, a gourmet cook, a biotech entrepreneur, an opera tenor and a science writer. All articles by Brian Dodson

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44 Comments

Any chance storing the excess electricity from the solar panels as cryogenic air for use in an on board Dearman esque engine would mean that the air compressors might not need so much power to add more airflow? Does that make sense?

James Tarquin Davis

22nd August, 2013 @ 03:00 am PDT

To avoid the strong lateral G forces of turns with smaller radii, the seats within the capsule could be made to uniformly swivel parallel to the vector of acceleration. This would be experienced by the passenger as more tolerable anterior-posterior G-forces rather than lateral acceleration.

This could be a passive mechanical-spring correcting seat configuration for simplicity.

Marcus Kornmehl

22nd August, 2013 @ 05:11 am PDT

@Marcus: I assumed that the whole capsule would / could rotate within the cylindrical tube, riding up the sides around the corners much like you do when you slide down a tube slide at a water park, or like the bank on the turns of an oval NASCAR track. If this happens (and it would need to be tightly controlled, I'd guess, at those high velocities) then there is no need to rotate the passengers independently. It would just naturally occur with the capsule's rotation. I think this would be necessary, anyway, with the "ski" design, as you want the relatively narrow skis to be oriented to support such g-forces and avoid contact between the capsule walls and the tube walls.

A bigger challenge that I see is maintaining the precision surfaces of the tube's interior required to maintain a sub-millimeter gap that appears to be needed for the "air bearings" to operate properly, given such high velocities. That sucker's gonna have to be smoother than a baby's bottom, and defect-free along its entire length! Yikes.

MzunguMkubwa

22nd August, 2013 @ 06:01 am PDT

This is one of the best article ever to appear on Gizmg. Thanks due the author for (finally) showing how this scheme can work.

piperTom

22nd August, 2013 @ 07:41 am PDT

Why does this have to be for passengers. A less expensive way of introducing this is technology may be to first use it for mail and freight movement. Likely to be economical and provide a proof of concept this would entail fewer risks. Either a rail line or freight company may be the best to introduce it or be first customers.

Facebook User

22nd August, 2013 @ 07:59 am PDT

The problem is not with the engineering. The problem is the tube costs a fortune to build and without huge subsidizes the operation will not service the interest on the debt incurred to build it. It also lacks flexibility going from San Francisco to LA and an earthquake or terrorist takes out the LA terminal everybody already on their way are screwed; airliners divert to another airport.

This might have some value doing something like tying Chicago's various airports together so you fly into Midway and half an hour later make your connecting flight out of O'Hara.

Slowburn

22nd August, 2013 @ 08:16 am PDT

I like the idea but I don't think the seating position or "hyper-cramped" cabin space is not going to be a real world, viable proposition that the public will embrace.

Is this a transportation system for those in excellent health and fitness only? I know the leaned back position is supposed to be comfortable and saves space but it's not a real world option for the elderly, anyone with respiratory issues, people with weight issues, etc.

In the real world people need to be able to sit down, not just lie back. I'm sure the airlines would have loved to make an airplane they could load passengers into like a box into a cargo plane but it doesn't work that way. People know cheap when they see it and they associate cheap with small. Cheap is also associated with unsafe too. Not the message you want to send the public after spending a fortune to build it.

To knock it out of the park, they need to be able to sit down and stand up as well. Even if it's only in the center aisle. Sounds like a little thing but it's actually very important to many people. The size gives people an assurance and a comfort that will be critical.

Sized this small, this is a design that only the bean counters will love. I imagine if built like this they will wind up with freight hauling as the bulk of their business.

venusvegasvada

22nd August, 2013 @ 09:24 am PDT

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700 mph? in a enclosed tube?? Are you guys really buying this nonsence? GIVE ME A BREAK!!

The only prctical high speed system introduced in the last 25 years is the Northrop-Grumman track guided wing-in-ground effect vehicle.

That system outguns the mag-lev by a mile, one tenth the cost,yet seems to have been put on "hold" over politics.

It was also "shot" by a steam catapult system very similar to the system aboard Navy Aircraft Carriers.

hummer boy

22nd August, 2013 @ 09:25 am PDT

Interesting project...I did a project with my Daugherty Olea 10 years ago.

A 50 person shuttle in vacuum tunel through tres Maria's mountains.

Cuernavaca center Mexico City in 11 minutes.

Nils J. Tvengsberg

22nd August, 2013 @ 09:27 am PDT

I have to differ on the suggestion that the Hyperloop cost estimates are being under-represented--but only if we agree that Musk were to run the project.

All public projects suffer from cost inflation, mostly this is due to the warped incentives of RFP contract pricing that includes line item payments on a percentage of total project costs under the added intoxicating influence of litigious business environments that force excessive redundancies into design and execution practices, simply to check boxes and create a paper trail in preparation for when one gets sued. And one always gets sued on big, expensive public projects with multiple and diverse vested interests all wanting a piece of the action.

If Musk were to do a prototype with private investors you can bet that his costs would be exactly the 1/10th of what you expect the public teat would be forced to squirt out. Exactly the cost savings he's already proven he can achieve on big public projects formerly run by government agencies and beltway bandit contractors through SpaceX manufacturing and launching rockets.

Who knew? He did.

Socialwealth

22nd August, 2013 @ 09:55 am PDT

Cooling of the bypassed air makes sense for two reasons. It minimizes insulation required for the passenger compartment and it helps to avoid heat buildup within the tube. There will be dozens of pods in the tube at any moment, so the air temperature would rise rapidly if the heat isn't carried to the terminal. I assume that it will be used to generate electricity at that point.

Rex Donahey

22nd August, 2013 @ 10:13 am PDT

This seems like such a specialized and expensive proposal, that

solves a limited number of problems in a few locations. Schemes like SkyTrans that are lower speed, but easier and cheaper to roll out (and expand) as well as be used for intra city transport seem far more promising and a far smaller gamble. Surprising that Musk did not mention that Goddard was his predecessor. Undoubtedly he found Goddard's patents on this while researching for his space ventures.

Michaelc

22nd August, 2013 @ 10:32 am PDT

It appears that near the ends of the tube (San Francisco and LA) it will come near the San Andreas fault and other faults.

tflahive

22nd August, 2013 @ 10:39 am PDT

Where are the restrooms? And what do you do in the middle of the tube when something breaks? Love the Idea. But I believe Politics will crush this dream unless someone can come up with some brilliant solutions.

Ryandroid86

22nd August, 2013 @ 01:24 pm PDT

Lateral acceleration is not a problem; the capsule would "bank" up onto the side walls of the tube, so the passengers would experience only "downward" force relative to their seats while going around curves. There's no reason the seat backs couldn't adjust between sitting and reclining for comfort. But standing is a no-go; the accelerations are too strong, particularly the forward and back accelerations from the linear induction motors.

Note that the lateral acceleration can reach 1.12g before the passengers will experience a total 1.5g of acceleration. (1g down + 1.12g sideways = 1.5g at an angle.) So even at 760mph, the turn radius can be as tight as 10km; there is such a tight turn shown southwest of Fresno on the hyperloop route map.

A more severe unaddressed issue is the "passive" thermal expansion and contraction of the tube. Even if the pylon-tube bearings were made incredibly efficient (coefficient of friction 0.001, about as good as the best ball bearings), the compression/tension on the tube through the tighter curves will still be massive, resulting in a huge tendency to push the tube sideways off the track, equivalent to about 10 tons per pylon pushing laterally at 1g continuously: first one way in the morning, then the other way in the evening. It's unlikely the current pylon design could handle this. Active longitudinal movement of the tube would be required to solve this, and/or perfectly straight vacuum expansion joints every few miles, itself a highly nontrivial engineering problem.

Finally, if the tube were severed at the top of the Grapevine, you wouldn't want 50 miles of continuous tube sliding unchecked downhill into Sylmar! That would not be pretty. Again, active control of the tube positioning is required, and/or expansion joints. Hopefully the "beta" version of the Hyperloop proposal will address these issues.

Ben Weiss

22nd August, 2013 @ 02:17 pm PDT

To expensive. To complicated. I beg people to look at something a little more practical. Please look at Skytran.net. Everywhere you see a row of telephone poles this system could be built. It is basicly an update of a G.M. system of the mid sixties. This system, would put thousands of americans back to work. Lyndon Johnson said in '64 if you were to give every one in the world [2000] sq. feet, You would just fill up Texas. If from the air, if you look down on a city [Any city in the world} You see three things--Roads [Driveways,alleys,parkinging lots] --Roofs-- And greenspaces. If you combine the Roads--and --Roofs. Your greenspaces will be bigger. So, build it over head. This will work.

Ryal White

22nd August, 2013 @ 02:57 pm PDT

Choked flow could be avoided or at least severely reduced if the following were observed:

1. deep grooves on the outside of the tube to permit passage of air

2. pipe or pipes through the center of the tube from front to back

Adrian Akau

22nd August, 2013 @ 03:24 pm PDT

I'd like it if Elon Musk put his money into the space elevator so he could fly rockets between London England and Sidney Australia using the space port for the up and down part of the trips. The spaceport ends of the space elevators would be the place to build the asteroid defense system. (We need that for defense eventually for sure, but all the time in consideration of the rogue asteroid similar to the rogue wave.)

Russell Scott Day

22nd August, 2013 @ 03:26 pm PDT

Impressive in depth analysis not available elsewhere. I do think the larger diameter version would provide a better return for a marginally greater investment. Well thought out management of thermal loads.

ConcordLift

22nd August, 2013 @ 03:59 pm PDT

Brian - you are awesome! This the best article I have seen on Gizmag yet, and just the sort of analysis I was looking for on the web. Keep them coming and ask the boss for a pay rise along the way!

MarkB

22nd August, 2013 @ 04:42 pm PDT

Great article, great comments. Finally someone tells me what i want to know.

Kim Holder

22nd August, 2013 @ 05:18 pm PDT

Like to see these routes:

LA to Denver, San Diego, Tuscon, Palm Springs, Tempe or Portland via Sacramento.

& to widen interior by 4 across??

& must have escape hatches & tunnel exit ways for escape IF unimaginable happens.

Or have route from Wash DC to NY to Boston to Miami to Memphis to Pittsburgh.

Stephen N Russell

22nd August, 2013 @ 06:01 pm PDT

To research, develop, and prove the technology, a smaller scale system ought to be built first, with both a smaller payload and a shorter track, and proportional speed. This could be a used in practice for delivery of materials within a city, or at an even smaller scale within a building, say a an automated factory or warehouse.

In order to be cost effective, is there a minimum size, or a maximum size?

With passengers, if the angle of the reclined seats cannot be changed, it might be easier to board and unboard while the car is at an angle such that the seat bottoms are horizontal.

Daniel LaLiberte

22nd August, 2013 @ 07:59 pm PDT

Rex

Cooling the bypassed air would reduce the thrust available. Heat buildup in the tube would not be an issue - total heat rejected to the tube is minute compared to the surface area of the tube available to dissipate heat.

Tony Morris

22nd August, 2013 @ 09:45 pm PDT

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as usual Brian Dodson has given us a detailed an well written article with facts and figures not arbitrary conjecture, Thank you Brian I always appreciate the quality of your articles and try to ignore the inevitable neigh sayers in the comments sections.

I agree with Marc B, A pay rise is well in order, Well done.

Develocon

22nd August, 2013 @ 09:59 pm PDT

BTW, better to take pee before you take off as there don't seem to be any toilets on board. And if they do have some don't face into the wind.

Facebook User

22nd August, 2013 @ 10:00 pm PDT

Daniel, any meaningful prototype would have to be at full speed and

full scale, because the critical transonic aerodynamic effects (shock waves, stability issues, choked flow etc) won't show up the same way in a scale model. A 10-mile track (with 2g acceleration to get up to speed, and 2g deceleration to stop) should be sufficient to shake out much of the necessary engineering, except for the long-distance thermal expansion issues as I mentioned above.

Ben Weiss

23rd August, 2013 @ 12:13 am PDT

As Musk himself has suggested, excess electricity generated can be used to recharge the onboard batteries of each capsule. But we could take that further depending on the amount of the excess.

Each Hyperloop station, or intermediate locations, could have plug-in and induction recharging points for electric vehicles. This, we hope, would encourage the wider use of electric vehicles in urban environments, such as for local delivery vans and taxis.

Thus, Hyperloop would not merely be a rapid transit system, but would form the backbone of an electric transport infrastructure.

David F

23rd August, 2013 @ 12:40 am PDT

@ Stephen N Russell

There is no need for emergency exits. If something bad happens there would be no survivors.

Slowburn

23rd August, 2013 @ 06:44 am PDT

Brian, thank you for a very informative article. I am hopeful that we will see this concept expanded as a national stimulus agenda, but propose that we first incline ourselves to include a smart grid initiative alongside this project.

Enabling ambient superconductors in a hardened, elevated construct... tied to various large-scale renewable energy systems and expanding the concept to include smaller, autonomous components that can exit and join at various intersections - running continuously in multiple directions - is the only way this can ever expand to full, societal use.

What I envision is something larger and actually slower, that enables people to stand up, mingle and move about, and have an ability to move from one autonomous car to the next, with each having the ability to drop off, exiting at select intersections along routes. Some components might travel entirely from LA to Miami, without ever stopping... a constant ebb and flow of separate, linked components.

The proposed system I'm seeing here will be very expensive and limited to those who can most afford it, rather than creating a system that every American can afford and should benefit by. The goal should be to enable each and every citizen to travel from West Coast to East Coast and points in between, with a lower cost and lower footprint than existing technologies.

I would love to sit in on a session with Elon and his engineers and share a vision that would create the largest jobs stimulus ever seen, and encompass the means by which all of us could view the scenery of our great country, silently, 50 feet above the earth, powered by the

sun and wind. If you can dream it, it can be… and I have dreamt it.

He and his team have certainly demonstrated their ability to turn ideas and concept into reality, but I'm afraid, like the Concorde, it would only serve the wealthiest amongst us. It's time to stop serving the wealthiest and think more humanely about the future. Elon has a great vision, but I am hopeful he will look at how to expand this to more individuals and enable all of us to improve our living standards and do so in a futuristically, more-sustainable way…

JD Howell

23rd August, 2013 @ 09:57 am PDT

But I gotta go pee!

How do you handle the simple acts of getting up to go to the bathroom or a human emergency without the ability to move around the cabin or capsule as it is being called here. Will the system be stable enough to allow people to move around the capsule? I am 6'3" there is no way I am going to be able to move around in a capsule this small unless I crawl. Is there going to be flight attendants of sorts to provide help for an individual that is having some sort of emergency?

Some simple questions that would need to be answered before this technology can become a commercially viable solution.

Greg Garman

23rd August, 2013 @ 02:41 pm PDT

Choked flow could be avoided or at least severely reduced if the following were observed:

1. deep grooves on the outside of the tube to permit passage of air

2. pipe or pipes through the center of the tube from front to back

Adrian Akau

Those were my first thoughts too Adrian but 'choked flow' could be done away with by building a square tunnel running a capsule with a round cross section through it, this would leave lots of room in the corners to let the air pass by. A square cross section is not so easy to twist on the corners but it could be done to match the centrifugal forces for a given fixed speed.

Elon's plan is doable and is very exciting, but a couple of concerns that I have are; the fine tolerances within the tube that the air bearings need to function properly, admittedly they would for the most part be self adjusting, e.g. more pressure = more gap, less pressure = less gap, but even so, maintaining a smooth inner wall to the required tolerances would take some doing. Next we have the issues of thermal expansion and contraction to deal with, hmm, don't know how to get over that unless you can maintain an even wall temperature from inside the tube. And this thing could be dangerous if something went wrong while traveling at the speeds envisioned and… what about the drunk dude blowing holes in it with his 50 cal rifle from the outside, or worse, a terrorist with dynamite, I shudder to think about it.

Facebook User

23rd August, 2013 @ 09:39 pm PDT

Hi Greg, Yeah I know what you mean, I'm 6'4" and my kids are even taller.

I'm pretty sure that I have seen something like this transport system in a B grade Sci-Fi movie on more than one occasion.

I think Elon's still thinking alone the lines of space travel, why not build it wider, taller and a bit slower, who cares if it takes an extra half hour to get to your destination if you get there in comfort rather than laying like sardines in a can. And who knows, there might even be room inside for a beverage vending machine (and a bathroom).

Dan

Facebook User

23rd August, 2013 @ 10:18 pm PDT

Questions.

I haven't read the the 57-page Hyperloop plan but, how do they plan to sequence all these capsules, pods, cars or whatever to stop them rear-ending each other if there are a lot of them in the tube at the same time?

What happens if the capsule in front of yours has a mechanical failure and is forced to stop and they are far away from an emergency exit point? It could get messy.

Dan

Facebook User

23rd August, 2013 @ 10:29 pm PDT

Slowburn, in the event of a severe earthquake, ALL of the capsules would emergency-stop in the tubes, per the alpha design. You would then have thousands of quite-living passengers stuck in the tube. (5600 at full capacity.) Escape hatches would be very necessary in this event.

Ben Weiss

24th August, 2013 @ 02:25 pm PDT

I think the right question is - in how many seconds can the bullet stop in case of ...earthquake !

Emil

25th August, 2013 @ 03:31 am PDT

"But I gotta go pee!

How do you handle the simple acts of getting up to go to the bathroom or a human emergency without the ability to move around the cabin or capsule as it is being called here. Will the system be stable enough to allow people to move around the capsule? I am 6'3" there is no way I am going to be able to move around in a capsule this small unless I crawl. Is there going to be flight attendants of sorts to provide help for an individual that is having some sort of emergency?

Some simple questions that would need to be answered before this technology can become a commercially viable solution.

Greg Garman"

No idea if the hyperloop is feasible or not, but this problem you mention is a non-issue. The entire trip takes half an hour. On a normal commercial airliner, the time from closing the doors and pushing back

from the terminal to the time when passengers can get up and use the bathrooms is at least that long. Clearly we are used to transportation that prevents you from using the bathroom for 30 minutes at a time.

mycommentemail

25th August, 2013 @ 07:17 pm PDT

In the 1970s I designed 'Envirotram'. This too used an elevated track with high-speed mag-lev trains running on top. Suspended below on each side of the pilotis hung 'trams'. These trams were two and three storey caravans or living pods with a detachable tractor unit at the front. This could be used for slow speed economical '

suspended travel' touring when not towing the living pod. Slung from the back of the pod or envirotram unit could also be a small runabout car, or boat. The theme really was 'countryside, clean-air, pollution-reduction, and the increased leisure time we were promised that would result form the 'computer-age'. New motorways cost millions per mile to build and rail travel is much cheaper than road. Water transport is the cheapest 'kilogram of rice per kilometre' cost which was the yardstick in the seventies. The envirotram elevated roads would criss-cross the world.

The elevated roadway besides carrying the living units below and the high-speed trains above, carried vacuum tubes for goods, and services such as pipes for sewage, and water.

The elevated roads would be comparable in cost to build to fresh motorways as they would have minimal footprint, and could be constructed similarly to the extrusion of toothpaste, with trucks running back and forth over the already built road, and cranes hanging out the end to support the formwork for the new.

The raison d'etre of the living unit, the tram, was to be based on the then-future concept of holographic television and computer communication. Work, or other, meetings could be conducted with several people sitting round a table with only one being real in the flesh and the others being projections.

The tram computer would be programmed for the destination, which could be anywhere the road went, then the residents could sit back and enjoy travelling at a sedate pace to wherever they wished, or just park-up in a secluded backwater, or city park. If they needed to go to the city or somewhere quickly, they could drive there directly in the tractor-unit to a nearby main road above road train station or ascend to the elevated road from the tram/caravan/envirotram and take a high-speed cab to the nearest main-line station point.

When parked in a tram-parc, permanently, semi-permanently, or transiently, their in-board computer would alert the vacuum delivery system of their position and provisioning requirements.

Where the terrain requires things would be a bit more rustic with the tram becoming a cable-car, and the computer provisioning put on hold. In this case, the residents would rely on a small vehicle slung on davits out the back, or a boat if over water.

I designed this project in order to reduce the enormous waste of carbon resources and with the intention of making communication faster and more efficient. I exhibited several A3 size panels at the Ceolfrith Arts, Sunderland Arts Centre 'Aerial Structures Exhibition' organized by the artist Lloyd Gibson September 1973. Since then I have emigrated to Australia over thirty years ago, but still have two of the original coloured panels which I can copy and forward if anyone is interested. I remember at the time my ideas was to free the ground for

people and elevate the traffic out of the way, but nearly everyone who saw it thought it would be an abominable way to live.

I also have a copy of the original 'Aerial Structures Exhibition Sept-Oct. 1973' catalogue.

That's ENVIROTRAM in a nutshell. Let me know if you want copies of the piccies.

Cheers,

Edward Houghton-Ward. Australia 2486.

Edward Houghton-Ward

25th August, 2013 @ 09:21 pm PDT

I don't see the complexities as deal breakers. Even if it doesn't do the entire route in 35 minutes, it could still work and be a huge help for California. Anyone who has ever driven in a car on an Interstate and not peed for more than an hour and a half should be able to handle the Hyperloop. More thoughts here.

Doug Bergman

26th August, 2013 @ 01:00 pm PDT

Brian, can you talk in detail about maintenance of the hyperloop? Let's say we build it, and 10 years, 20 or 30 years down the road, what kind of things do we need to maintain on a daily, weekly, monthly or yearly basis? I assume the air bearing, which is capable of lifting a pod of 5 tons (I assume), must damage the tube slightly. So some maintenance must be done on a regular basis, but how? In DC, every time metro does work on the track, we get long delay. So at the end, any benefits from using metro are gone. For the hyperloop, to avoid this problem, I feel it should have a third tube that can go either direction to be used when one of the tubes is in maintenance mode.

What would happen if while travelling at 760 mph, one of the 28 pairs of air cushion skis stop working? Let's say the first pair in front. Would the pod grind against the tube at 760 mph? What would happen if the compressor stops working and no air comes out of all the 28 pairs of cushion skis?

Johnny Le

26th August, 2013 @ 04:28 pm PDT

Regarding the need for cooling, the expanding gas at the rear of the pod would be cooled considerably. The expanded gas could be a good place to dump a significant amount of heat.

James Donnaught

29th August, 2013 @ 08:56 pm PDT

A concept is being presented but nobody really seams to be in touch with reality. Tubes are used in transportation industry for a long time and are regulated by many governmental bodies including OSHA. First issue:

Very closely spaced Emergency Exists will be required, as specified by OSHA, as well as walkways connecting them. In addition you will need stepping platforms with stairways that will connect the ground with the Emergency Exists. [I forgot but the c-c distance for the

Emergency Exits in tubes is something like 150 feet.]

That is only one detail that is very obvious. This concept has so many holes it resembles Swiss cheese.

Paul D. Cervenka

1st September, 2013 @ 06:57 pm PDT

While The Hyperloop is a much faster monorail/train system it doesn't really solve any issues that current public transportation already offers - the ability to go from place A to place B along a designated route. If one were to use our BiModal Glideway system you'd be able to travel from door to door without relying on changing trains, busses or leaving your car in a lot during the day where it could be vandalized.

Tony Alvarado

24th September, 2013 @ 12:32 pm PDT

If the capsule is canted or tilted as it goes around a turn, the passenger would not feel a 0.5 G lateral (sideways) acceleration. This is the same effect as when a roadway for a car is tilted as we go around a turn, to lessen the preceived lateral accelarations. A 0.5 G lateral acceleration adds to the 1.0 G downward pull of gravity for a vector sum of 1.12 G at an angle of 27 degrees to the vertical. So it if the Hyperloop capsule is tilted at 27 degrees during the high speed turn, the passenger would feel 1.12 G downward toward their seat, or they would feel "12% heavier" which would not be a problem at all. The passenger would not feel any lateral acceleration. This is standard practice for highways, for high speed trains, for planes, or for race tracks, and Elon Musk mentioned that his can be done when he presented the Hyperloop.

FrankYashar

31st October, 2013 @ 03:34 am PDT

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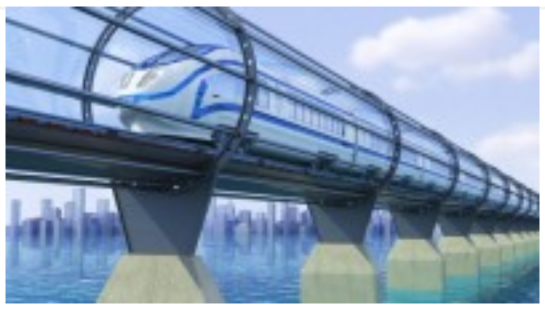

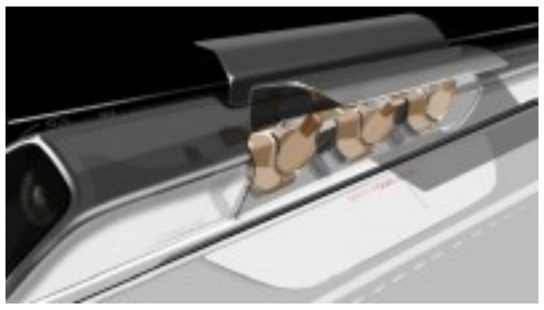

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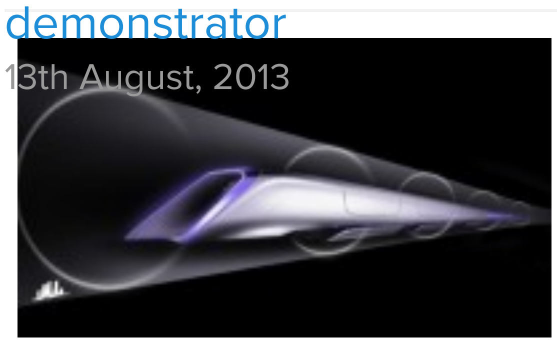

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